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Scheduling Colonoscopy Patients Under Uncertainty

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HEALTHCARE ENGINEERING & PATIENT SAFETY
UNIVERSITY OF MICHIGAN

Research Team

- Systems Concepts for the Optimization and Personalization of Endoscopy Scheduling (SCOPES) Team:
  - Dr. Amy Cohn, Associate Professor, Industrial and Operations Engineering
  - Dr. Sameer Saini and Dr. Jacob Kurlander, The University of Michigan Health System (UMHS) and the Vetrans Ann Arbor Healthcare System (VAAHS)
  - All CHEPS students who contribute to SCOPES

Presentation Outline

- Motivation and Overview
- The Offline Stochastic Colonoscopy Appointment Problem (OSSP)
- Properties of Approximated Scheduling Polices
- Conclusion and Future Directions

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Colonoscopy Procedure

- Gold standard for Colorectal Cancer (CRC) screening
  - 2nd leading cause of cancer-related death in the US[2]
  - 4.5 million age-eligible subjects in the US (≥50 years)[3]

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- Allows for direct visual examination of the entire colon and rectum
  - Spot existing cancer, prompting treatment
  - Prevent future cancer (***polyps***)

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- Allows for direct visual examination of the entire colon and rectum
  - Spot existing cancer, prompting treatment
  - Prevent future cancer (***polyps***)

- Can help reduce CRC incidence by about 40% and mortality by about 50%[1]

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Colonoscopy Appointment Scheduling

- One special characteristic of colonoscopy scheduling is the unique bimodal duration structure

Type-Duration	Prep Quality	Health Conditions	No. of Polyps	Type of Sedation
Easy-Short	Good	Good	Low	Conscious
Complex-Long	Poor	Poor	High	Anesthesia

* Note: also for some cases procedure is not performed

Colonoscopy Appointment Scheduling

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- Extra time flushing out colon

Colonoscopy Appointment Scheduling

- One special characteristic of colonoscopy scheduling is the unique bimodal duration structure

Type-Duration	Prep Quality
Easy-Short	Good
Complex-Long	Poor

- Significant variability in attendance, arrival patterns, and cancellations

Colonoscopy Appointment Scheduling

unique bimodal

duration structure

attendance, arrival patterns, and cancellations

Colonoscopy Appointment Scheduling

unique bimodal

duration structure

A schedule with many outliers

attendance, arrival patterns, and cancellations

Colonoscopy Appointment Scheduling

- Multiple conflicting criteria that affect the quality of schedule
  - Waiting, idling, overtime (this talk)
  - Appointment Time Preferences (future talk)
  - Procedure quality and Polyps detection (future talk)

Research Goal

- Needs a decision support tool:
  - Allocation of available slots to patient groups (resource allocation)
  - A list of daily appointment slots to offer for patients (template)
  - Instructions that tells how to assign individual patient requests to a slot in the daily appointment template (scheduling policies)

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  - A list of daily appointment slots to offer for patients (template)
  - Instructions that tells how to assign individual patient requests to a slot in the daily appointment template (scheduling policies)
- Things to consider:
  - Provider availability
  - Duration, arrival time, and attendance
  - Multiple criteria

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The Offline Stochastic Colonoscopy Problem (OSSP)

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  Patient order
  Appointment times

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- Second stage decisions (actual schedule)
  Arrival time
  Actual start time

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  Arrival time
  Actual start time
  Waiting, idling, overtime (metrics)

The Offline Stochastic Colonoscopy Problem (OSSP)

- Objective:

  Optimal scheduling decisions for a set of P patients, that minimizes the expected waiting, idling and overtime

- First stage decisions (generate a schedule)

  Patient order

  Appointment times

- Second stage decisions (actual schedule)

  Arrival time

  Actual start time

  Waiting, idling, overtime (metrics)

$$\text{OSSP} \quad v = \min f = \sum_{\omega \in \Omega} \phi(\omega) \Big[\lambda^W \sum_{i=1}^{P} (s_i^\omega - a_i^\omega) + \lambda^T \sum_{i=1}^{P} g_i^\omega + \lambda^O o^\omega \Big]$$

$$\text{s.t.} \quad \sum_{i \in P} x_{ip} = 1 \qquad \text{for } p = 1, \ldots, P$$

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Each patient is assigned is assigned to one position in the sequence

$$t_1 \geq 0$$

$$t_i \geq t_{i-1} \qquad \text{for } i = 2, \ldots, P$$

$$t_i \leq \mathcal{L} \qquad \text{for } i = 1, \ldots, P$$

Appointment times:
- obey the sequence
- within the clinic service hours

$$a_i^\omega = t_i + \sum_{p=1}^{P} u_p^\omega \cdot x_{ip} \qquad \text{for } i = 1, \ldots, P, \omega \in \Omega$$

Arrival time= scheduled$\pm$unpunctuality

$$s_1^\omega \geq t_1 \qquad \forall \omega \in \Omega$$

$$s_i^\omega \geq a_i^\omega \qquad \text{for } i = 1, \ldots, P, \omega \in \Omega$$

start time=max(arrival, completion of previous patient)

$$s_i^\omega \geq s_{i-1}^\omega + \sum_{p=1}^{P} \tau_p^\omega \cdot x_{i-1p} \qquad \text{for } i = 2, \ldots, P, \omega \in \Omega$$

$$g_1^\omega \geq a_1^\omega - t_1 \qquad \forall \omega \in \Omega$$

$$g_i^\omega \geq a_i^\omega - \big(s_{i-1}^\omega + \sum_{p=1}^{P} \tau_p^\omega \cdot x_{i-1p}\big) \qquad \text{for } i = 2, \ldots, P, \omega \in \Omega$$

$$o^\omega \geq a_P^\omega + \sum_{j=1}^{P} \tau_j^\omega \cdot x_{Pj} - \mathcal{L} \qquad \forall \omega \in \Omega$$

Idle time before the *ith* patient

$$g^\omega, o^\omega \geq 0 \qquad \forall \omega \in \Omega$$

$$x_{ip} \in \{0, 1\} \qquad \forall (i, p) \in \{1, \ldots, P\}$$

overtime

Parameters

$0 - \mathcal{L}$: clinic service hours
τ_p^w : patient p duration in ω
u_p^w : patient p unpunctuality in ω
$\phi(\omega)$: probability of scenario ω

Sequencing and scheduling variables

x_{ip} : 1 if p is the *ith* patient; 0 otherwise
t_i : scheduled time of the *ith* patient

Actual schedule variables

a_i^ω : arrival time of the *ith* patient under ω
s_i^ω : start time of *ith* patient under ω
g_i^ω : idle time before the start of the *ith* patient under ω
o^ω : idle time before the start of the *ith* patient under ω

The Offline Stochastic Colonoscopy Problem (OSSP)

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Parameters?!

OSSP Parameters: Type-based Duration Model

Type	Prep Quality
Easy-Short	Good
Complex-Long	Poor

OSSP Parameters: Type-based Duration Model

Type	Prep Quality
Easy-Short	Good
Complex-Long	Poor

- Type-duration likelihood 0.75

OSSP Parameters: Type-based Duration Model

Type	Duration
Easy-Short	$\sim f(\cdot)^{short}$
Complex-Long	$\sim g(\cdot)^{long}$

- Type-duration likelihood $\mathbf{0.75}$
- Continuous
  - e.g., if easy, then duration $\sim f(\cdot)^{short}$ with 0.75 probability or $\sim g(\cdot)^{long}$ with 0.25 probability

OSSP Parameters: Type-based Duration Model

Type	Mode
Easy-Short	30
Complex-Long	90

- Type-duration likelihood $\mathbf{0.75}$
- Continuous
  - e.g., if easy, then duration $\sim f(\cdot)^{short}$ with 0.75 probability or $\sim g(\cdot)^{long}$ with 0.25 probability

OSSP Parameters: Type-based Duration Model

Type	Lowest conceivable value (LCV)	Mode	Highest conceivable value (HCV)
Easy-Short	20	30	60
Complex-Long	60	90	120

- Type-duration likelihood $\mathbf{0.75}$
- Continuous
  - e.g., if easy, then duration $\sim f(\cdot)^{short}$ with 0.75 probability or $\sim g(\cdot)^{long}$ with 0.25 probability

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  - e.g., if easy, then duration $\sim f(\cdot)^{short}$ with 0.75 probability or $\sim g(\cdot)^{long}$ with 0.25 probability
    - $|N(\boldsymbol{\mu}_{s(l)}, \boldsymbol{\sigma}^2_{s(l)})|$

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- Type-duration likelihood $\mathbf{0.75}$
- Continuous
  - e.g., if easy, then duration $\sim f(\cdot)^{short}$ with 0.75 probability or $\sim g(\cdot)^{long}$ with 0.25 probability
    - **Three Sigma Rule**

$$\boldsymbol{\sigma_{s(l)} = \frac{HCV - LCV}{6}}$$

- $\boldsymbol{f(\cdot)^{short} = |N(30, 6.67^2)|}$
- $\boldsymbol{g(\cdot)^{long} = |N(90, 10^2)|}$

Solution Approach?

Constructive Monte Carlo Optimization Approach

See you at IFOR17,INFORMS17, POMS17, IISE18,…..

for m=1:M **do**

Step 1. ***Generate a sample of size*** N

- Generate N scenarios of $\eta_p(\eta_p^1....\eta_p^N)$, $\forall p \in P$
- Generate N scenarios of $\tau_p(\tau_p^1....\tau_p^N)$, $\forall p \in P$
- Generate N scenarios of $u_p(u_p^1....u_p^N)$, $\forall p \in P$

Step 2. ***Solve Sample Average Problem (OSSP(N))***

Let v_N^m be the corresponding optimal objective value

Step 3. ***Evaluation of the true objective function using Monte Carlo simulation***

3.1 Generate Nscenarios, solve *OSSP(N)*, and obtain $(\widehat{\mathbf{X}}^m, \widehat{\mathbf{t}}^m)$

3.2 Generate $N' >> N$ scenarios

3.2 Estimate the true value of the objective function $(\hat{v}_{N'}^m)$ using the schedule $(\widehat{\mathbf{X}}^m, \widehat{\mathbf{t}}^m)$:

$$\hat{v}_{N'}^m(\widehat{\mathbf{x}}^m, \widehat{\mathbf{t}}^m) = \frac{1}{N'} \sum_{n=1}^{N'} \Big[\sum_{i=1}^{P} \big(s_i^n(\widehat{\mathbf{X}}^m, \widehat{\mathbf{t}}^m) - a_i^n(\widehat{\mathbf{X}}^m, \widehat{\mathbf{t}}^m) \big) + g_i^n(\widehat{\mathbf{X}}^m, \widehat{\mathbf{t}}^m) + o^n(\widehat{\mathbf{X}}^m, \widehat{\mathbf{t}}^m) \Big]$$

end

Compute the average of v_N^m ***and*** $\hat{v}_{N'}^m$ ***overall replication:***

$$\overline{v}_N = \frac{1}{M} \sum_{m=1}^{M} v_N^m \qquad \overline{v}_{N'} = \frac{1}{M} \sum_{m=1}^{M} \hat{v}_{N'}^m(\widehat{\mathbf{X}}^m, \widehat{\mathbf{t}}^m)$$

Compute (Approximate) optimality indices

$$AOI_1 = \frac{\min\limits_{m \in M} (\hat{v}_{N'}^m) - \overline{v}_N}{\min\limits_{m \in M} (\hat{v}_{N'}^m)} \qquad AOI_2 = \frac{\overline{v}_{N'} - \overline{v}_N}{\overline{v}_{N'}}$$

Algorithm 1: *OSSP* Monte Carlo Optimization (OSSP-MCO)

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Approximated Scheduling Policy as a Function of Patient Mix

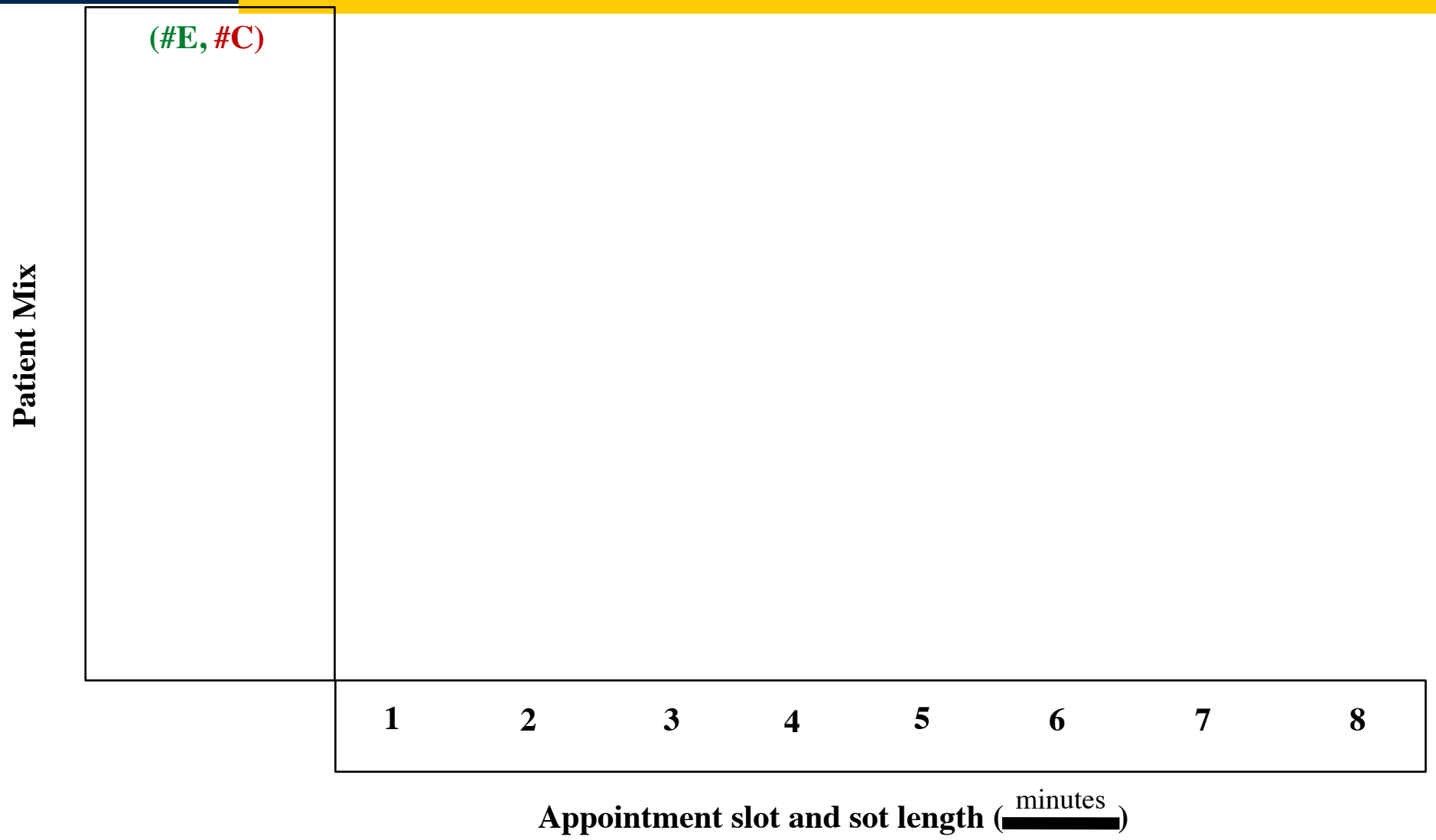
P=8 patients

$\tau^{E} \sim N(30, 3.36)$

$\tau^{C} \sim N(90, 6.67)$

Punctual

Approximated Scheduling Policy as a Function of Patient Mix



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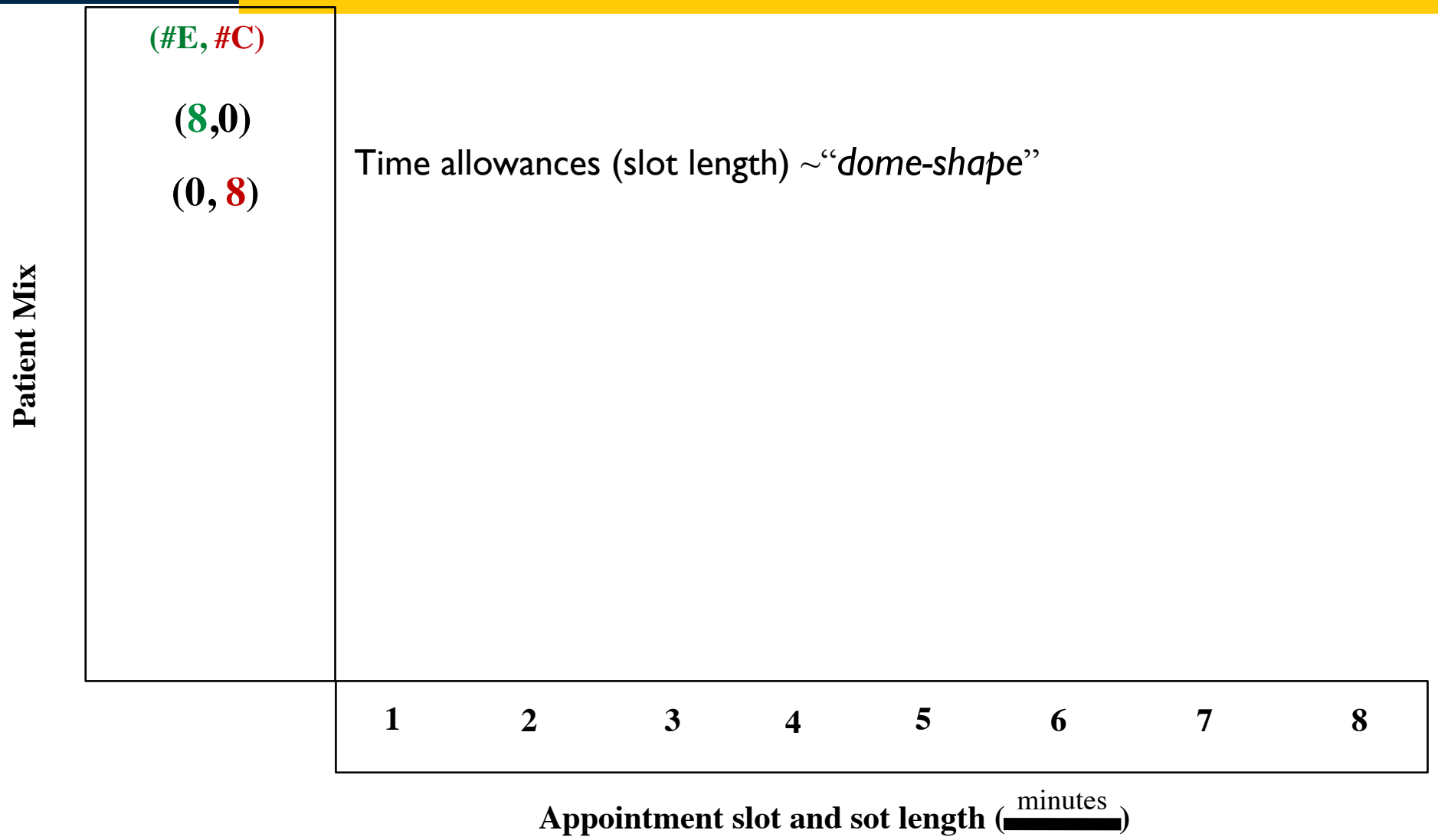
Patient Mix (#E, #C)	1	2	3	4	5	6	7	8
(8,0)								
(0, 8)								

Appointment slot and sot length (minutes)

Approximated Scheduling Policy as a Function of Patient Mix



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(#E, #C)

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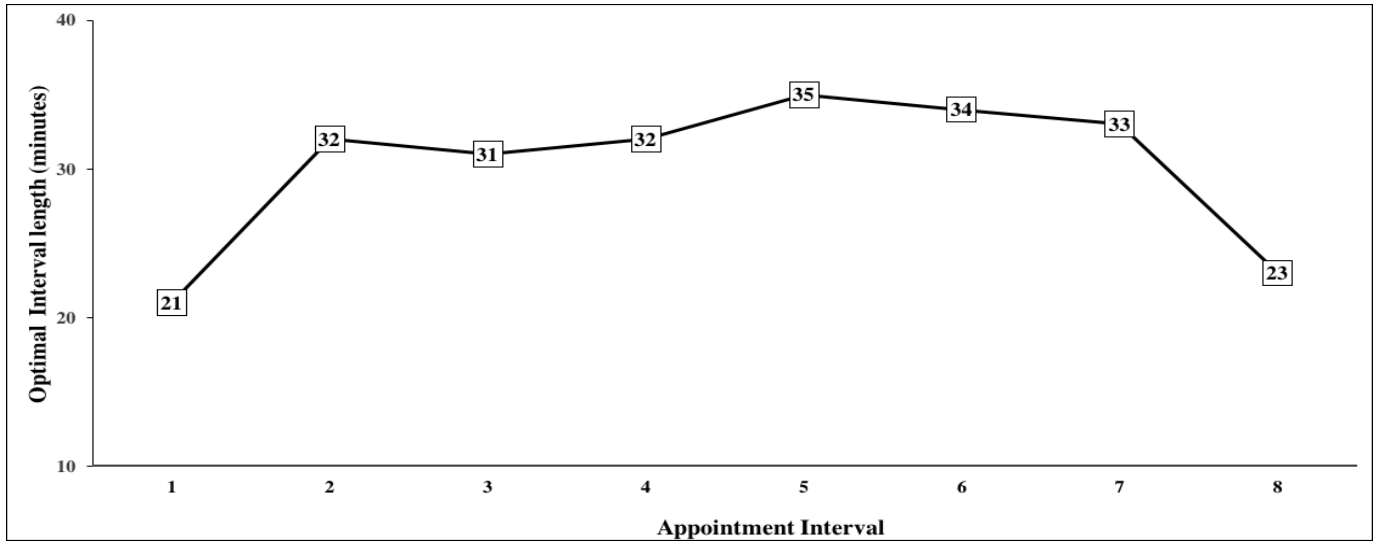
Time allowances (slot length) ~"*dome-shape*"



1 2 3 4 5 6 7 8

Appointment slot and sot length (minutes)

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Patient Mix	(#E, #C)	
	One Type	Time allowances ~"*dome-shape*"
	(4, 4)	

1	2	3	4	5	6	7	8

Appointment slot and sot length (minutes)

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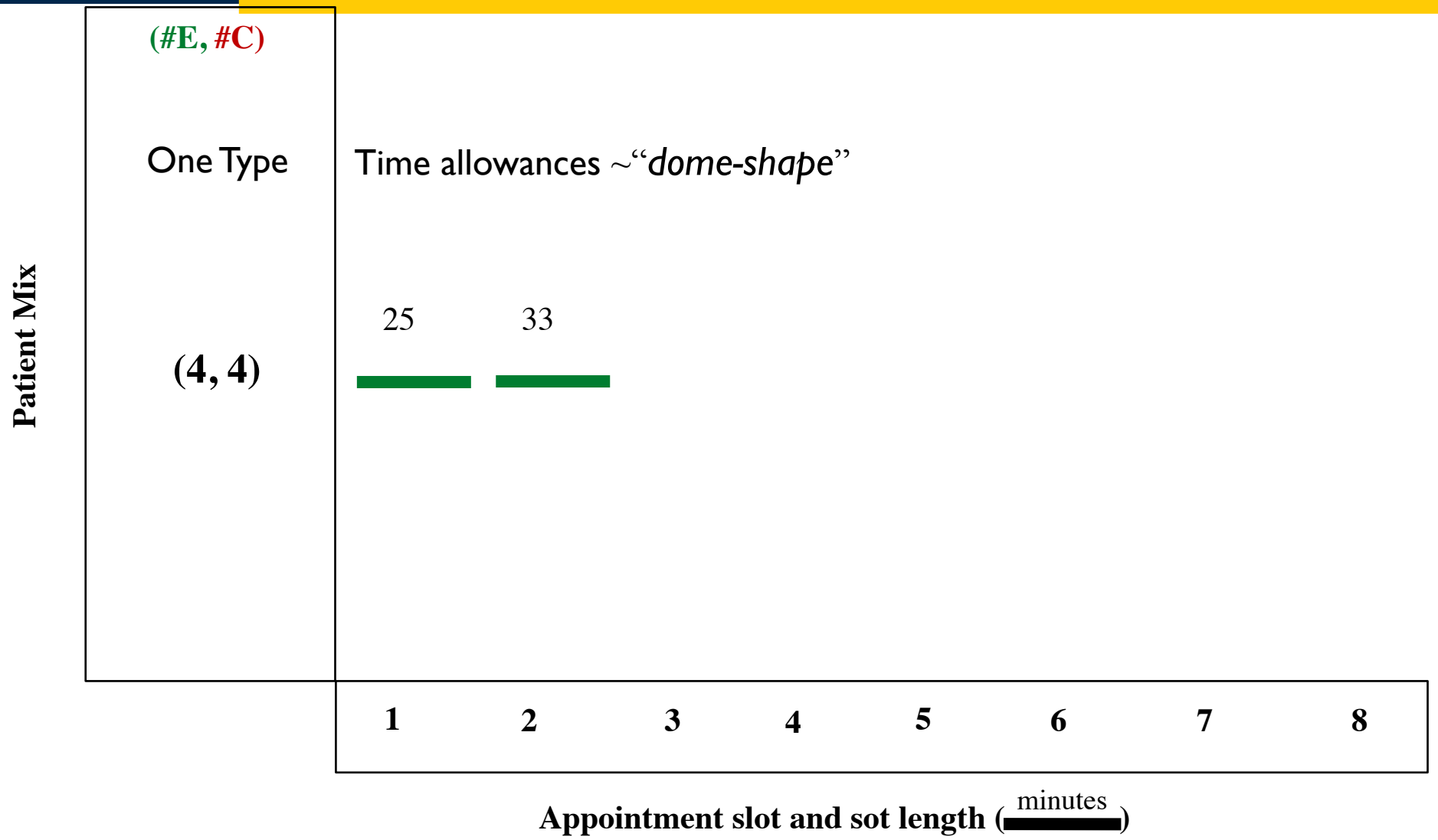

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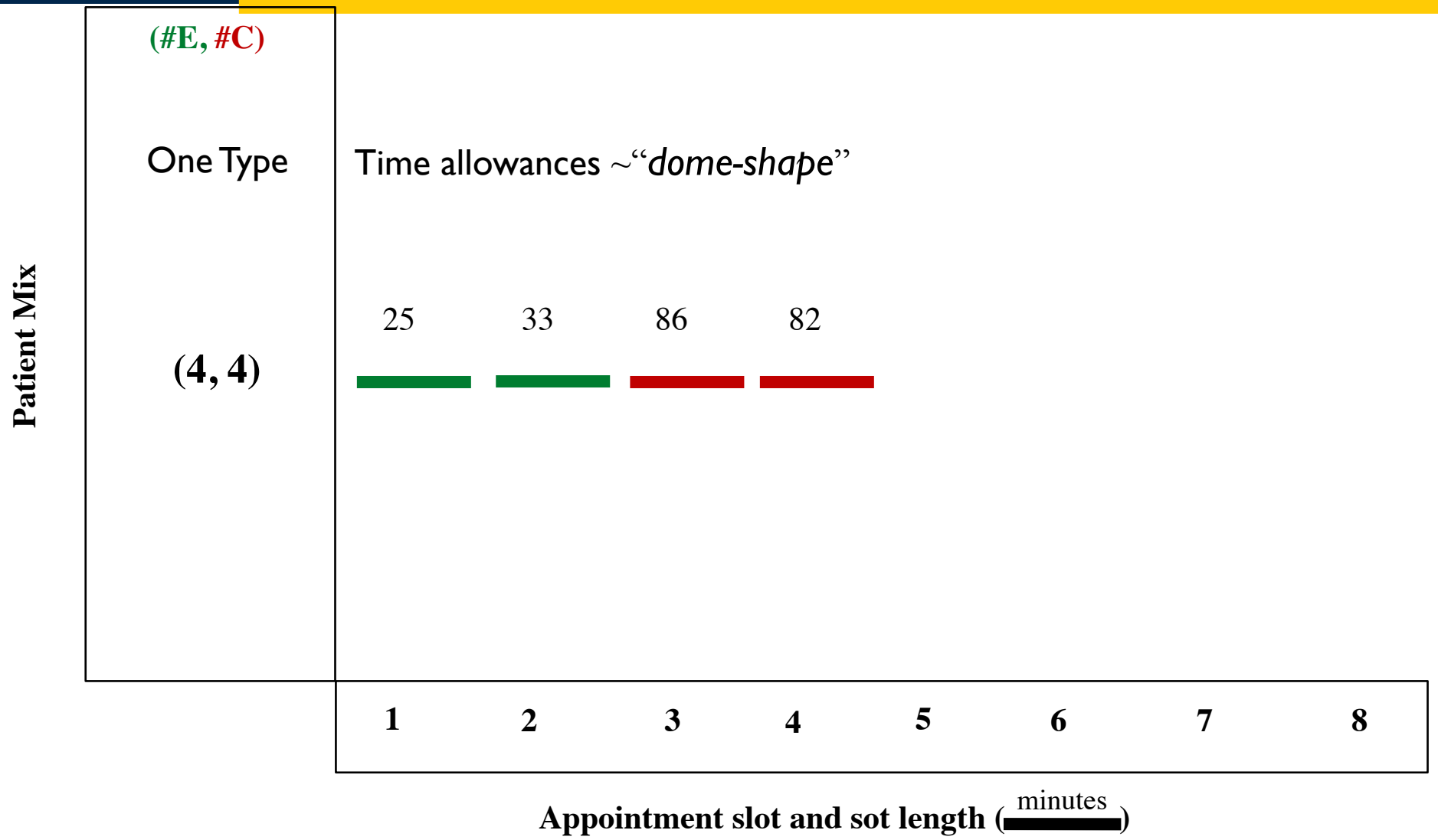

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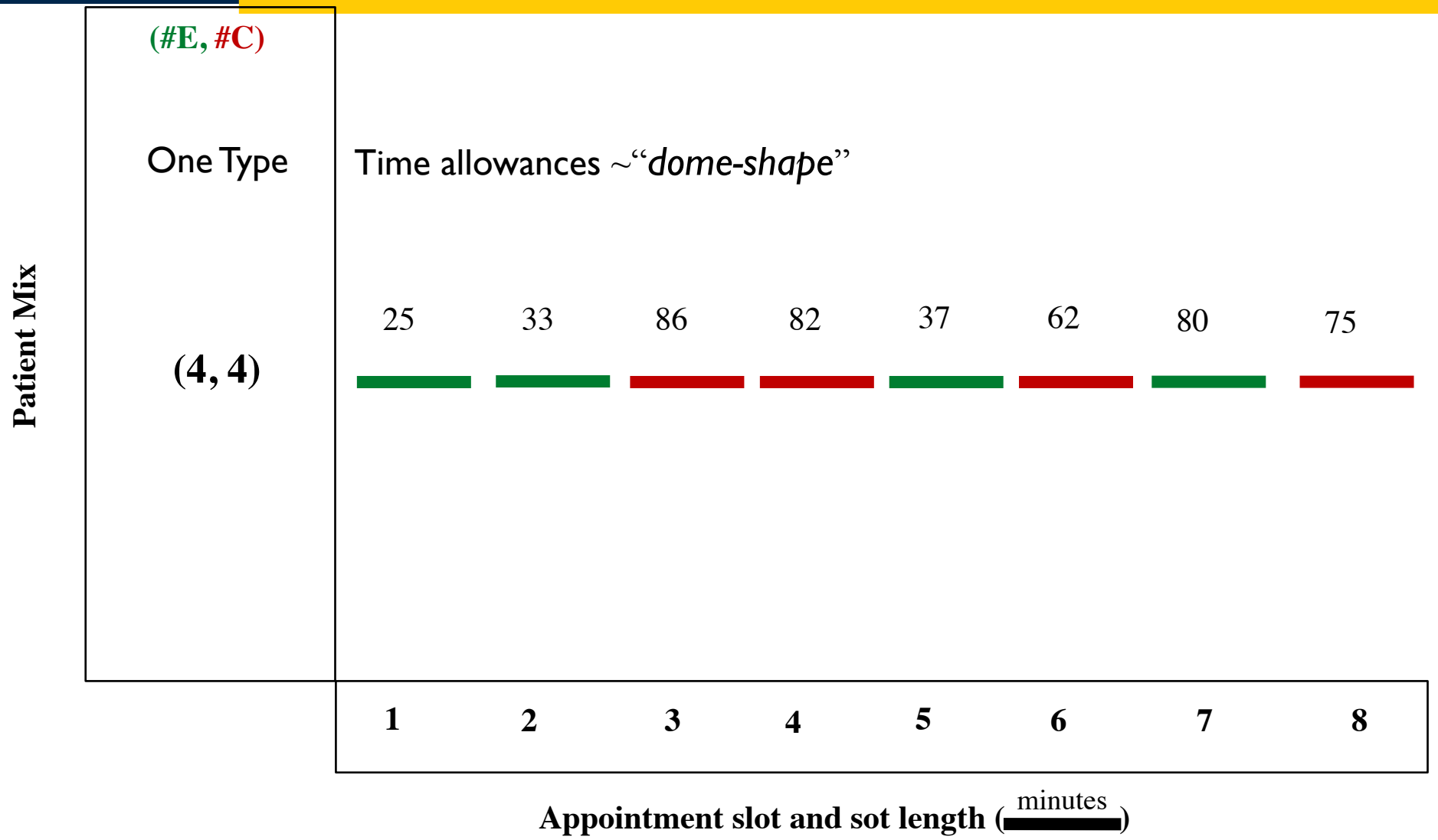

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Patient Mix (#E, #C)	
One Type	Time allowances ~"*dome-shape*"
Balanced Mix	Sequence ~ "*Alternating Buckets*" of **Easy** → **Complex** Time allowances ~ "*Bucket-based-Dome*"

1	2	3	4	5	6	7	8

Appointment slot and sot length (minutes)

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(6, 2)	

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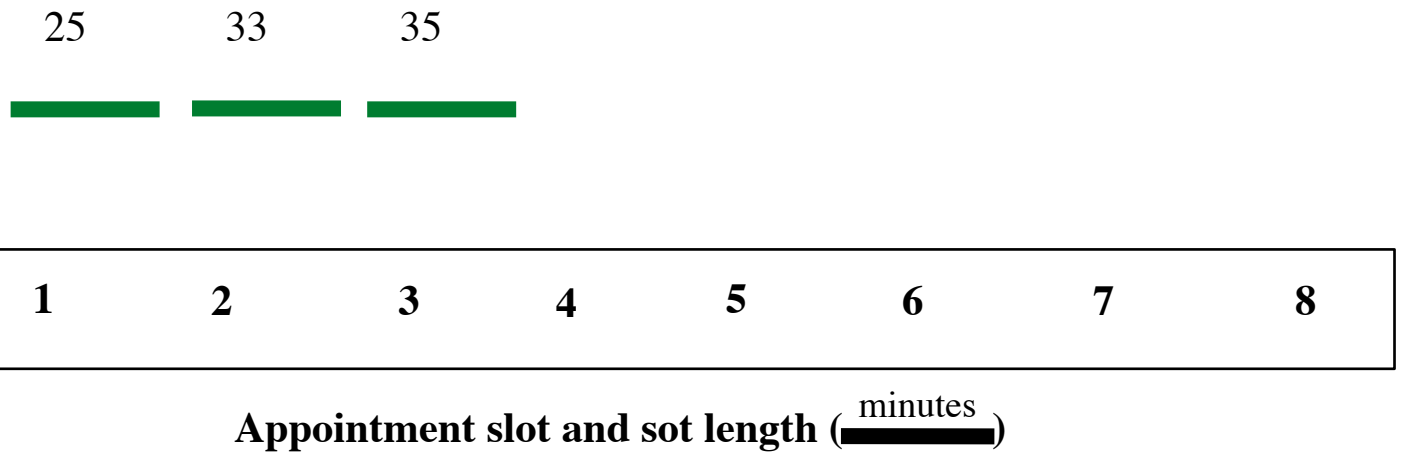

Appointment slot and sot length (minutes)

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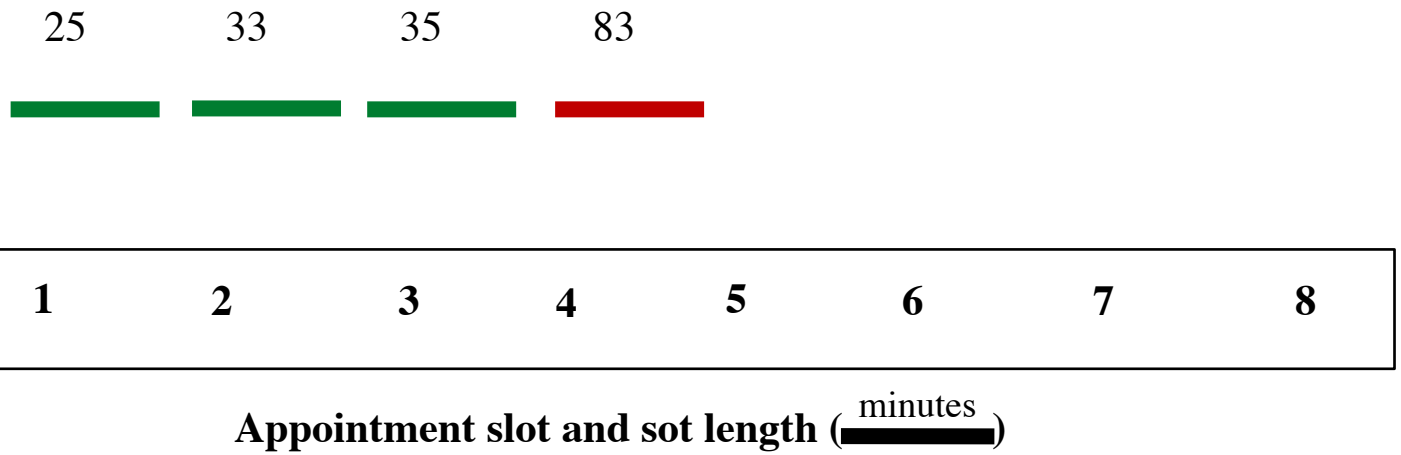

Appointment slot and sot length (minutes)

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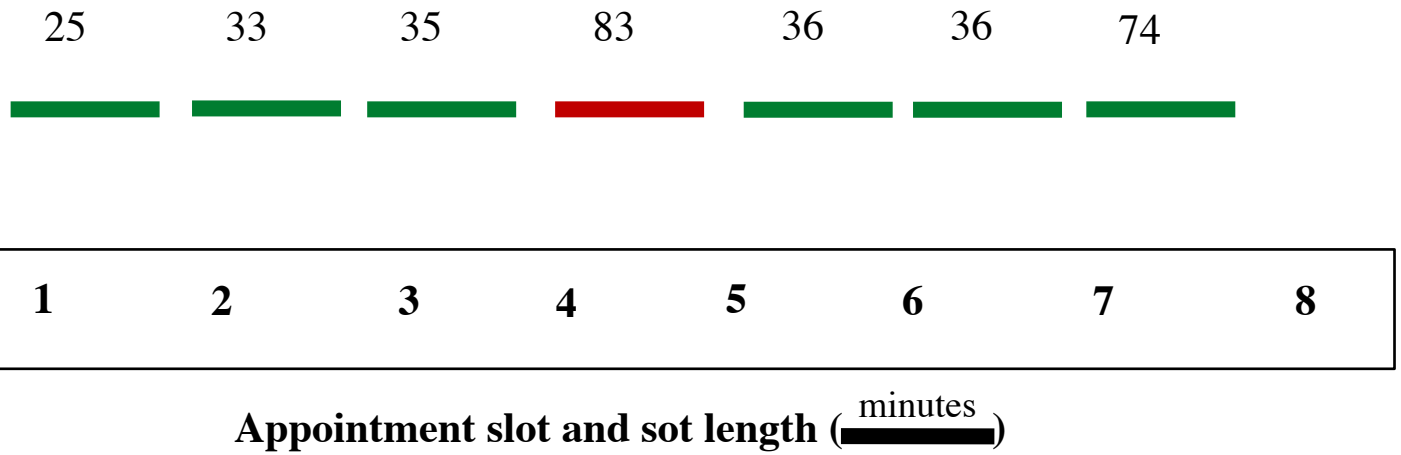

Appointment slot and sot length (minutes)

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Punctual

Patient Mix

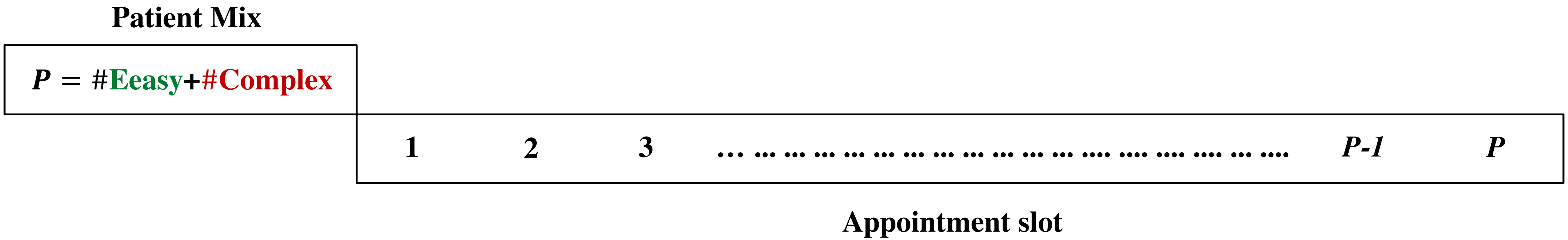
(#E, #C)	
One Type	Time allowances ~"*dome-shape*"
Balanced Mix	Sequence ~ "*Alternating Buckets*" of **Easy** → **Complex** Time allowances ~ "*Bucket-based–Dome*"
(6, 2)	25 33 35 83 36 36 74 42

1	2	3	4	5	6	7	8

Appointment slot and sot length (minutes)

Approximated Scheduling Policy as a Function of Patient Mix

Natural Question: how to leverage OSSP sub-problems properties in solving the more challenging OSSP versions?



Patient Mix

P = #Eeasy+#Complex

1	2	3	… … … … … … … … … … … … … …. …. …. …. … ….	P-1	P

Appointment slot

Approximated Scheduling Policy as a Function of Patient Mix

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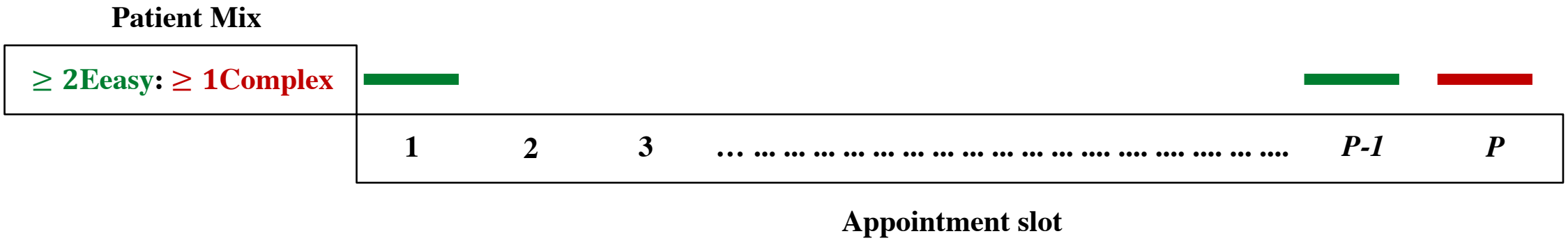
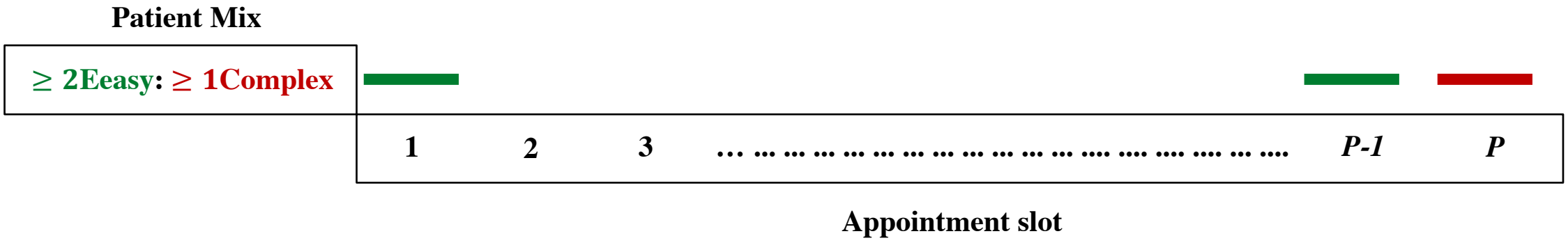


Approximated Scheduling Policy as a Function of Patient Mix

Natural Question: how to leverage OSSP sub-problems properties in solving the more challenging OSSP versions?

P=10, 5E:5C > intractable



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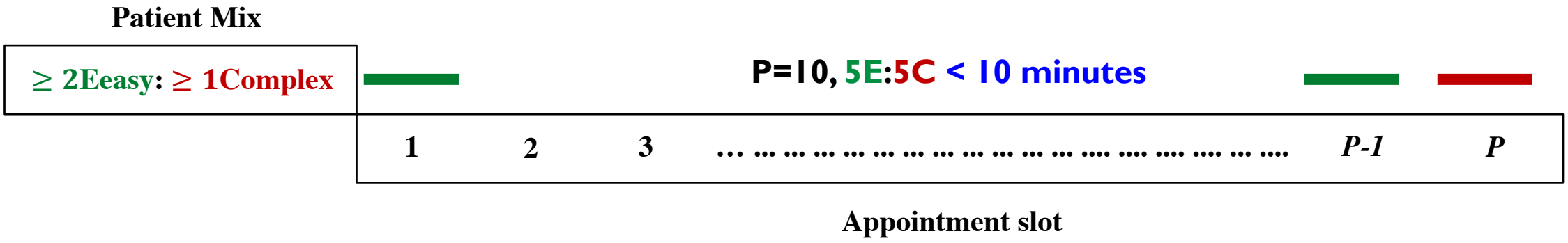

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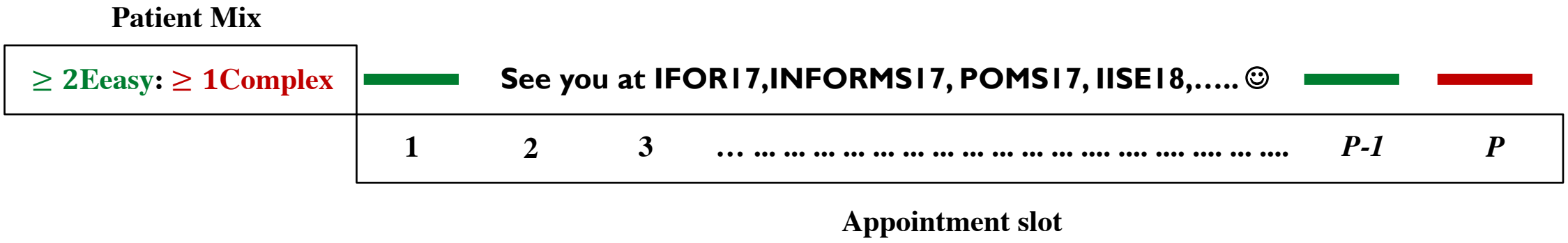

Sensitivity of Approximated Scheduling Policy to Arrival Patterns

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3Eeasy: 4Complex

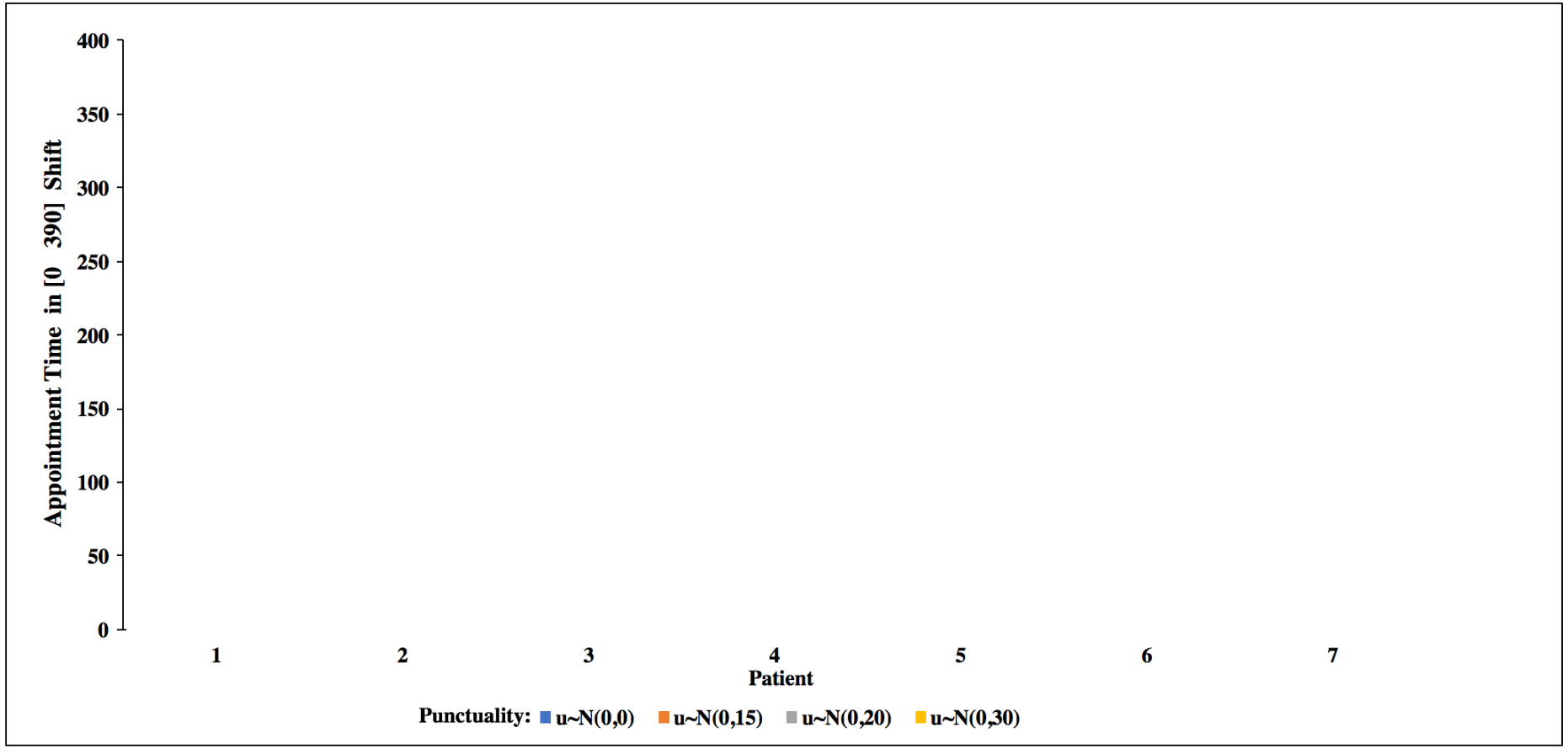

Figure 1. Sensitivity of the approximated scheduling policy to arrivals pattern. Patients are on average **punctual,** with a mean earliness of 0 minutes and a standard deviation of σ minutes.

Sensitivity of Approximated Scheduling Policy to Arrival Patterns

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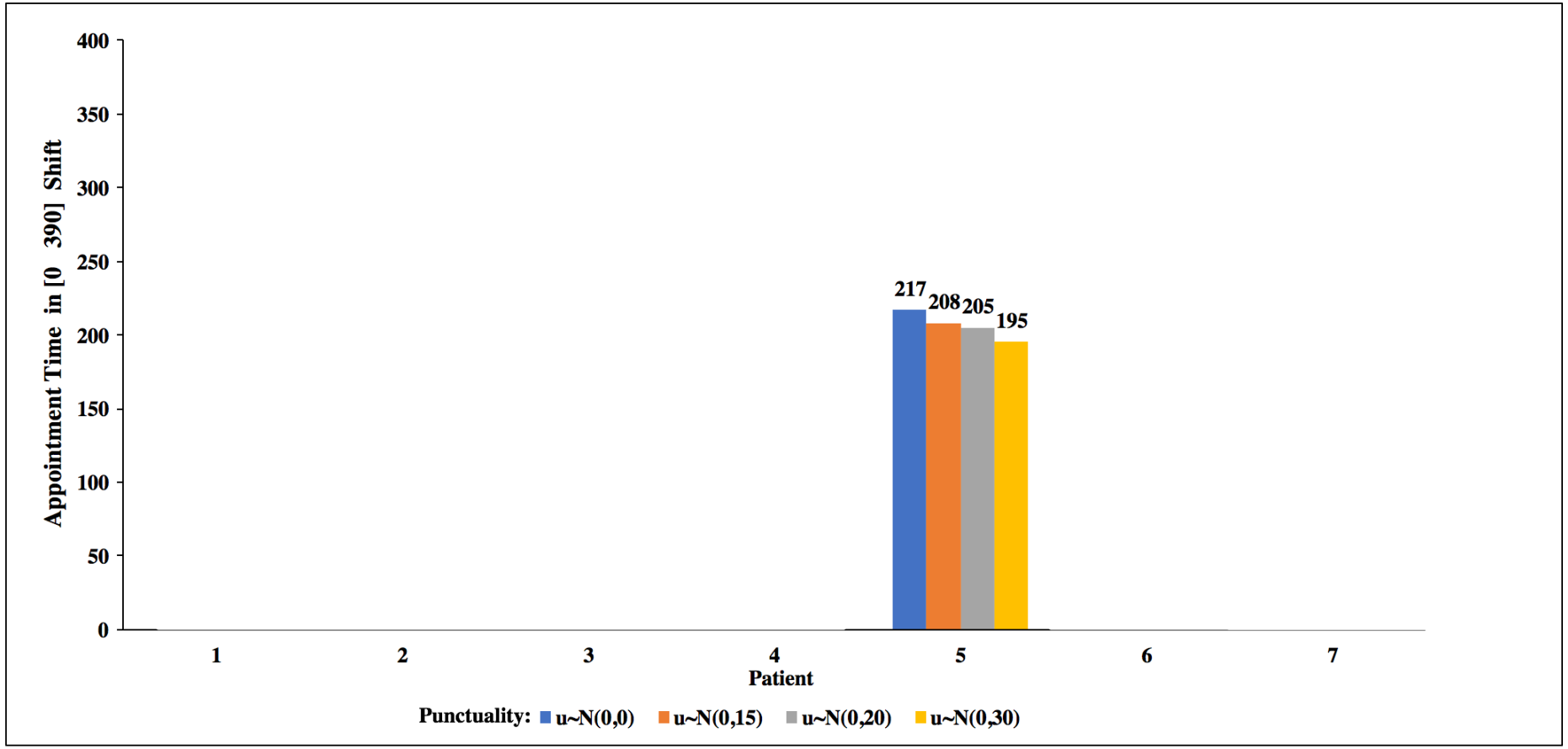

Figure 1. Sensitivity of the approximated scheduling policy to arrivals pattern. Patients are on average **punctual,** with a mean earliness of 0 minutes and a standard deviation of σ minutes.

Sensitivity of Approximated Scheduling Policy to Arrival Patterns

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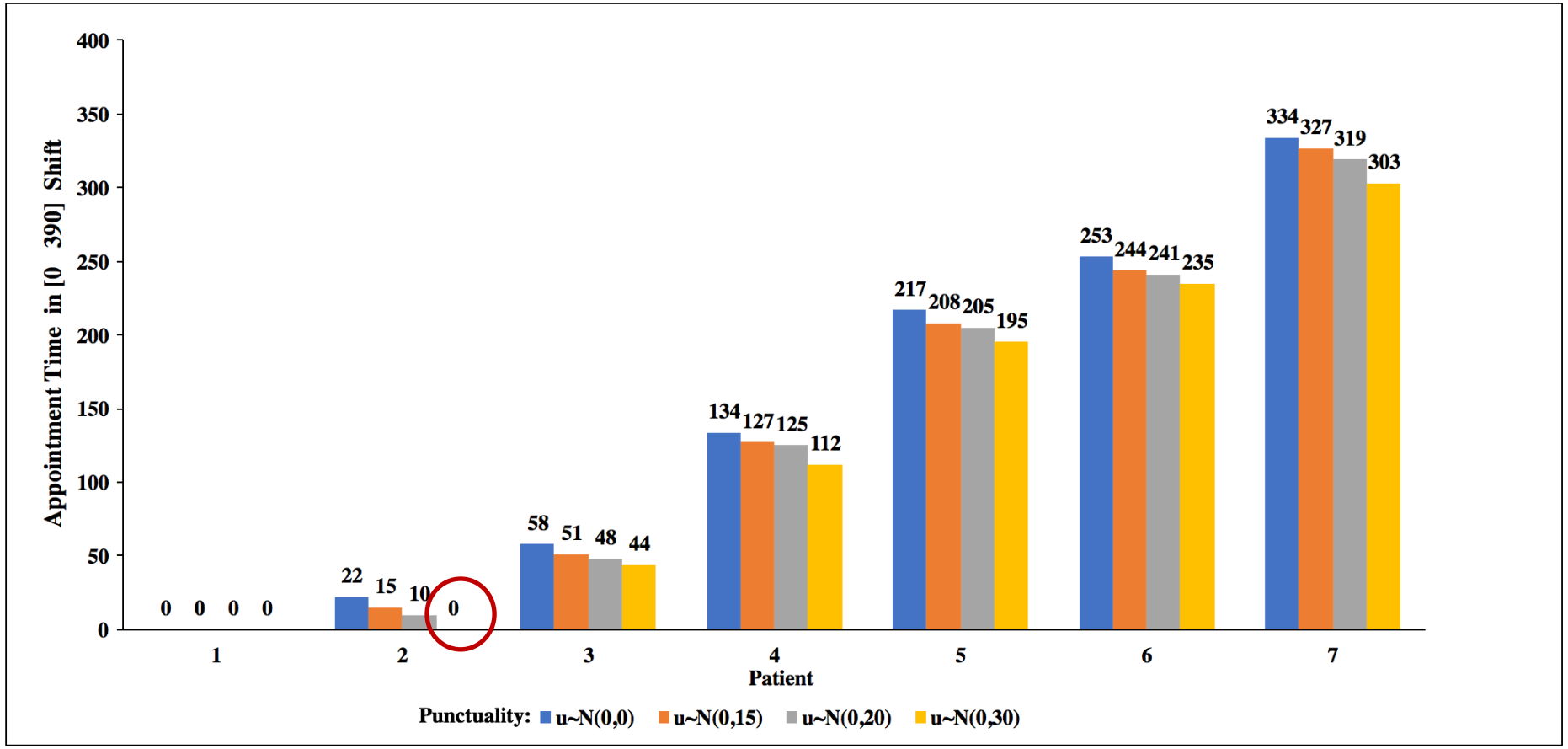
3Eeasy: 4Complex



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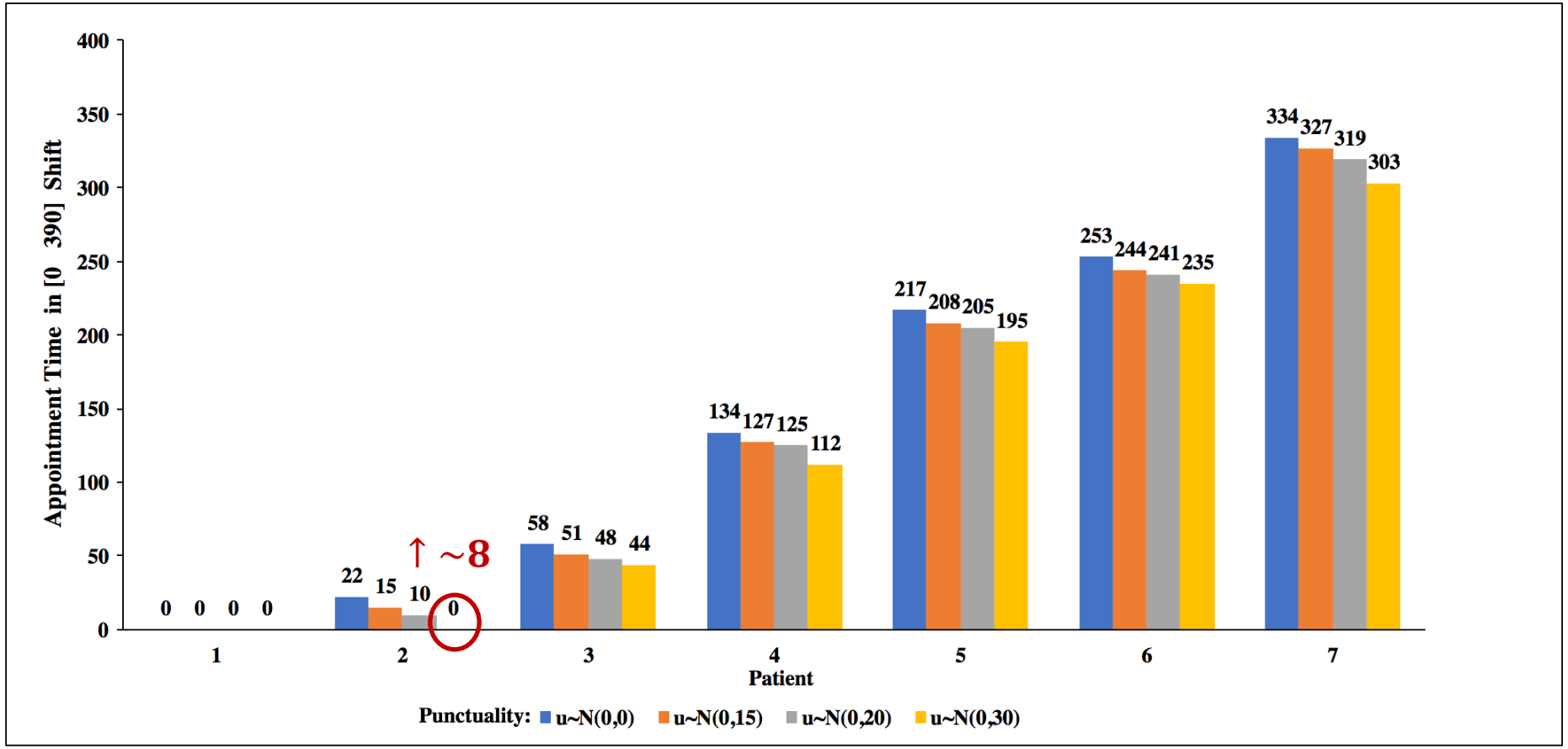

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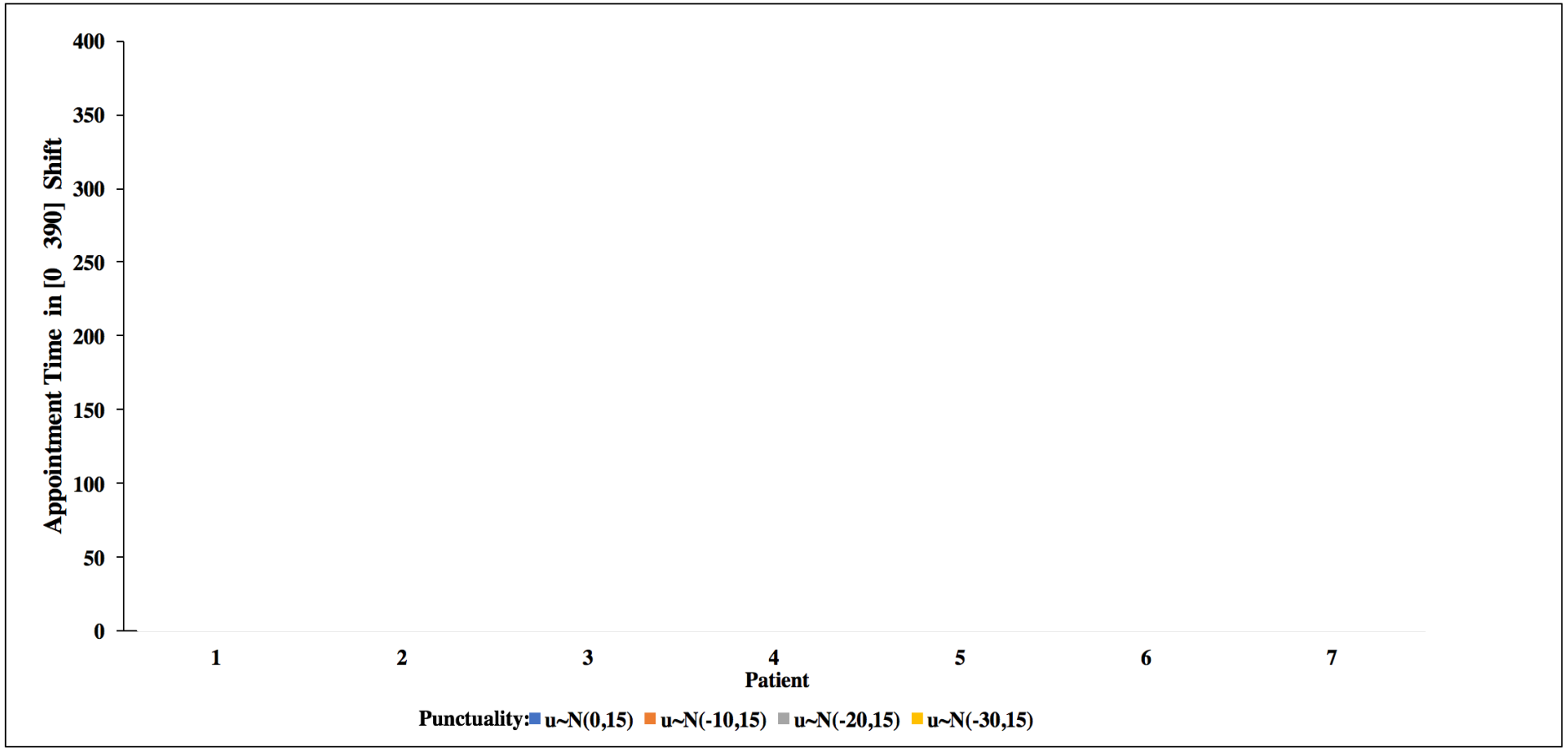

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Sensitivity of Approximated Scheduling Policy to Arrival Patterns

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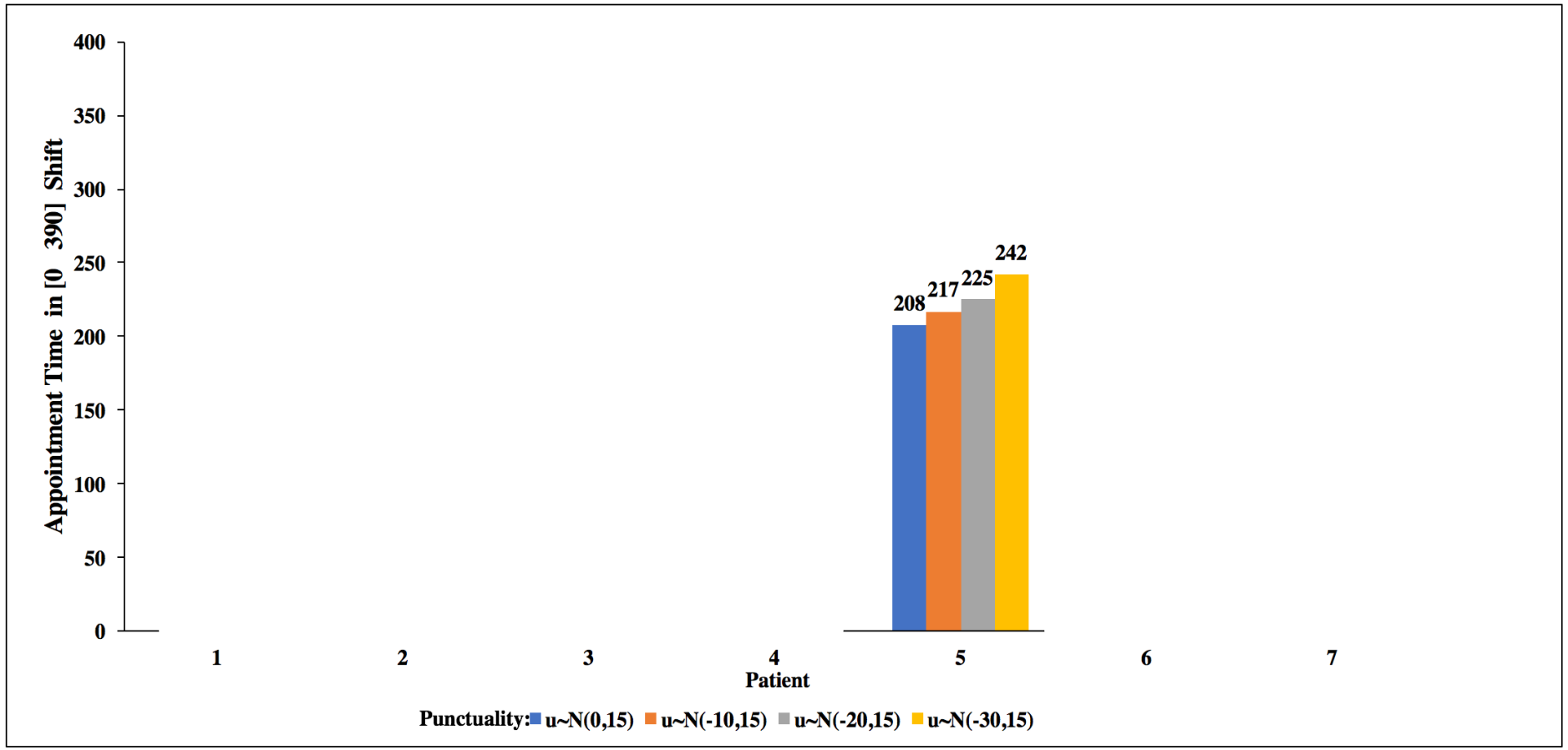

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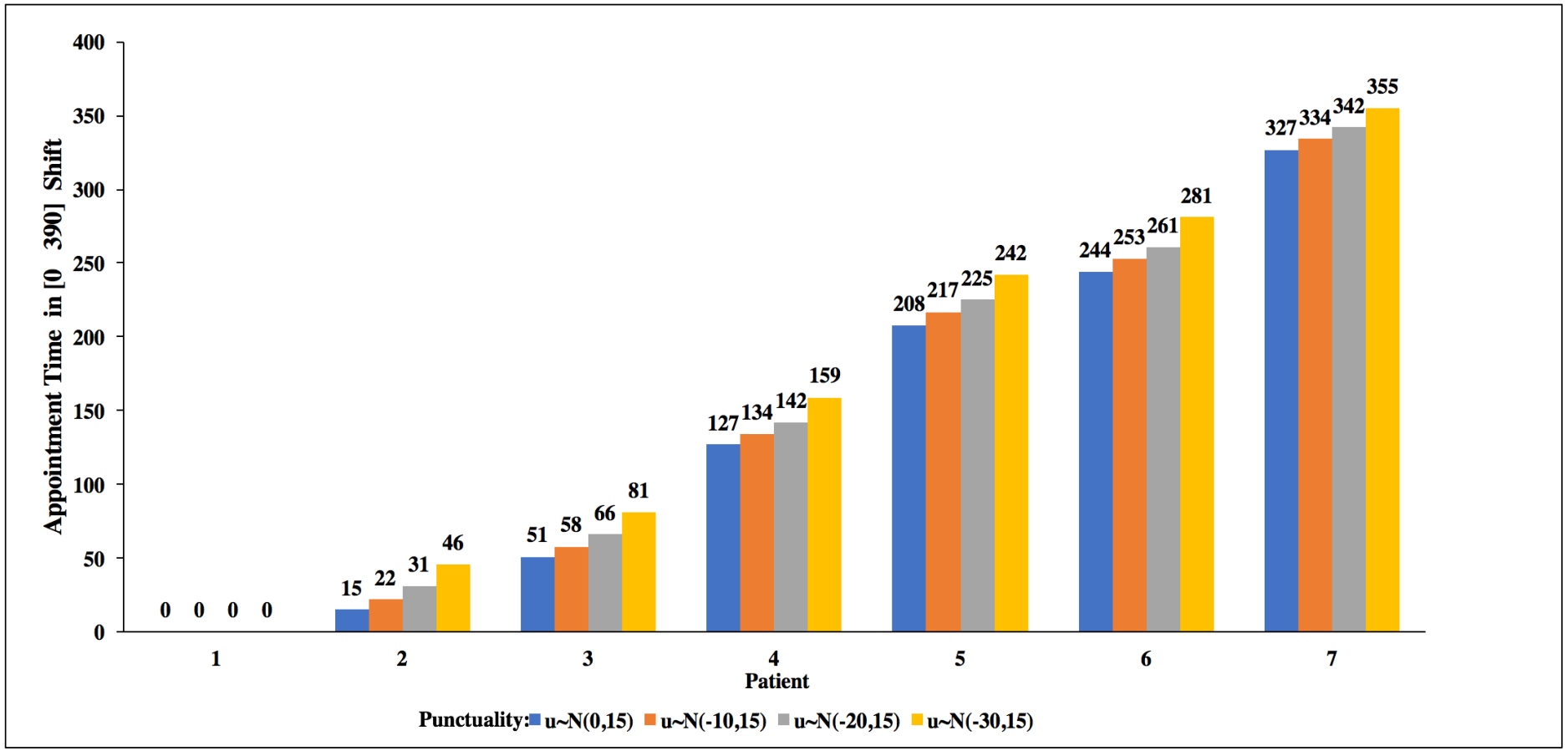

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Sensitivity of Approximated Scheduling Policy to Arrival Patterns

- Bimodality
- No-show
- Patient Risk and Preference

Sensitivity of Approximated Scheduling Policy to Arrival Patterns

- Bimodality
- No-show
- Patient Risk and Preference

How to Apply in Practice?

TEMPLATE REQUIREMENTS FORM

To determine which template to use, view this provider's visit type lengths and select the lowest common denominator. These lengths must match your service level standards to ensure departments across a service are consitant. **Click here to locate your department's service level standards.**

Your Contact Information

Form Completed By:	Karmel Shehadeh
Phone #:	607-744-1945
Uniqname/Email:	ksheha@umich.edu

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Phone #:	607-744-1945
Uniqname/Email:	ksheha@umich.edu

Department Information

MiChart Department Name:	Medical Procedure Unit
MiChart Department Number:	101021602

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Provider/Resource Full Name:	Donald Richardson
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Provider Uniqname:	Donalric
Subgroup:	GI

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Effective Dates

From:	5/23/17
To:	8/23/17

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Effective Dates

From:	5/23/17
To:	8/23/17

Monday				Tuesday			
Start Time			Stop Time	Start Time			Stop T
7:00		to	1:00 PM	___:___		to	___:
Time	# Open	# Ovbk	Block	Time	# Open	# Ovbk	Blo
7:00 AM	1	0	Easy-Colon	7:00 AM	1	0	Easy-Colon
7:20 AM	1	0	Complex-Colon	7:20 AM	1	0	Complex-C
8:20AM	1	0	Easy-Colon	8:20AM	1	0	Easy-Colon
8:50 AM	1	0	Complex-Colon	8:50 AM	1	0	Complex-C
10:15 AM	1	0	Easy-Colon	10:15 AM	1	0	Easy-Colon
10:55 AM	1	0	Easy-Colon	10:55 AM	1	0	Easy-Colon
11.:30 AM	1	0	Complex-Colon	11.:30 AM	1	0	Complex-C

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10:55 AM	1	0	Easy-Colon	10:55 AM	1	0	Easy-Colon
11.:30 AM	1	0	Complex-Colon	11.:30 AM	1	0	Complex-C

Submit the form to MICHIGAN MEDICINE TRANSFORMING. CREATING. LEADING. Cadence-IT folks

Example for Practical and Optimal Template

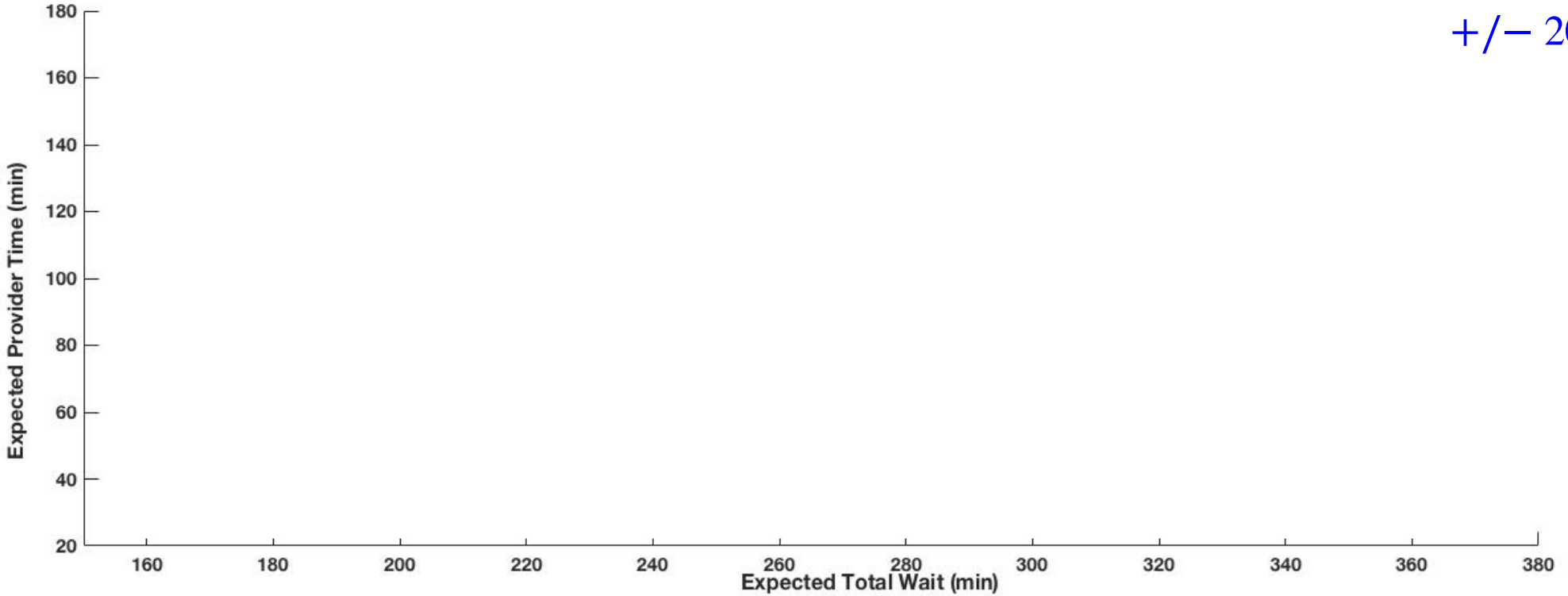
Duration +No-show+ 50% late

Monday			
Start Time			Stop Time
7:00		to	1:00 PM
Time	# Open	# Ovbk	Block
7:00 AM	1	0	Easy-Colon
7:20 AM	1	0	Complex-Colon
8:20AM	1	0	Easy-Colon
8:50 AM	1	0	Complex-Colon
10:15 AM	1	0	Easy-Colon
10:55 AM	1	0	Easy-Colon
11.:30 AM	1	0	Complex-Colon

Worth the computational effort??

Values of Stochastic Optimization in Colonoscopy Scheduling

3Eeasy: 4Complex
18% no-show rate
+/− 20 min early/late



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1,000 Days

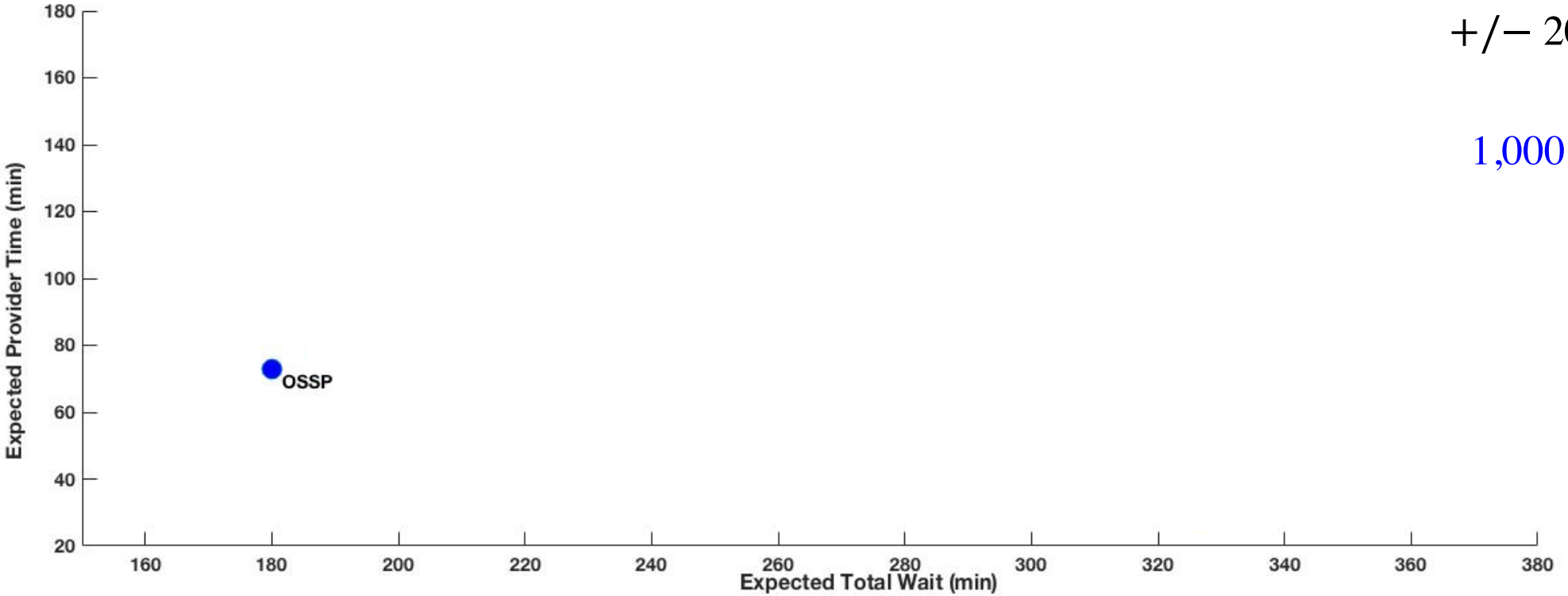

Figure 3. Expected performance of OSSP and some tradional scheduling rules under different levels of no-show and arrivals uncertainties. The case of $r = 18\%$ and $u \sim N(0, 20)$

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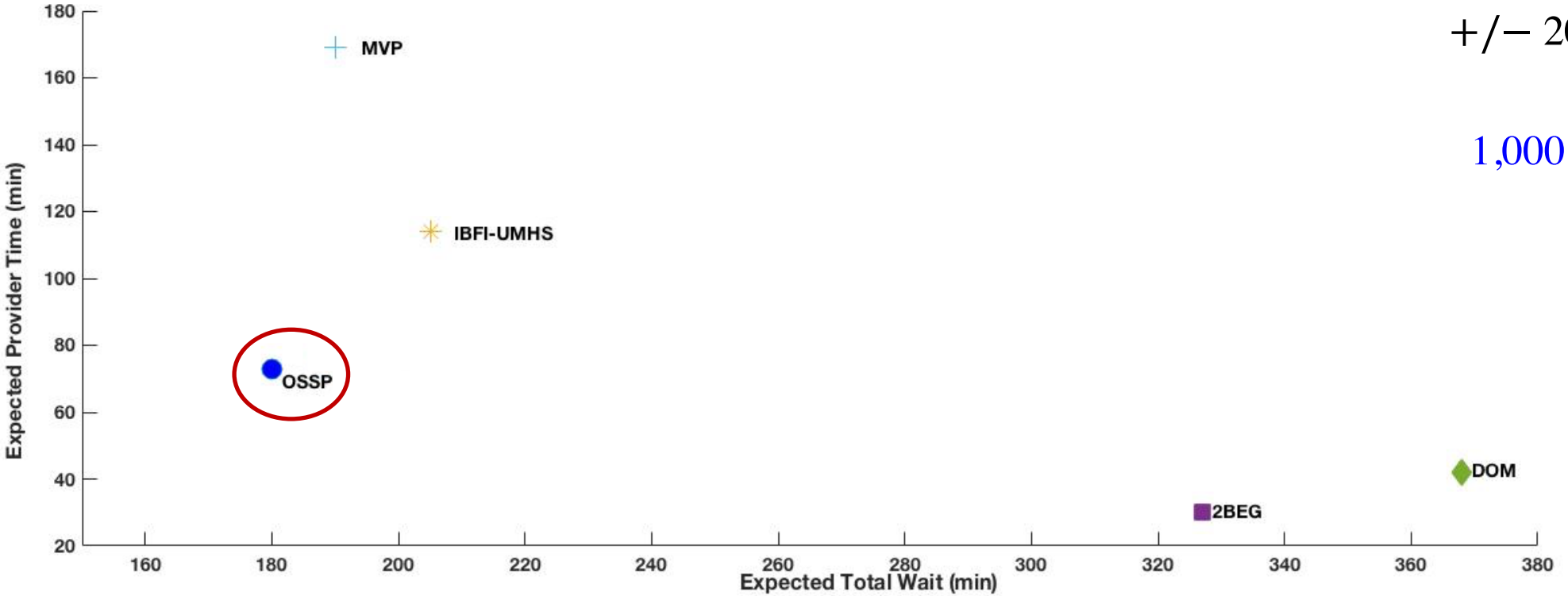

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Presentation Outline

- Motivation and Problem Overview
- The Offline Stochastic Colonoscopy Appointment Problem (OSSP)
- Properties of Approximated Scheduling Polices
- Conclusion and Future Directions

Conclusion

- Colonoscopy scheduling have unique characteristics that are different in nature and potentially different from other OPC

- Scheduling polices depends on the uncertainty within these characteristics

- Properties of the "Approximated" schedules can be exploited in designing appointment scheduling tool (system)

Importance?

- On-time Schedule
  - Less provider fatigue
  - More efficient performance
- Less Waiting
  - Better experience
  - Fewer cancelation
- More appointments
- Better Outcome!

Future Directions

- Methodology:
  - Incorporate patient outcomes and preference
  - Probabilistic models for duration, absenteeism and arrivals
  - Incorporate interaction effect of uncertain parameters
  - Tractable and efficient solution methods

- Practice
  - Bowel prep interventions
  - Universal template and scheduling polices

Acknowledgement

- My STAR Professor Amy Cohn
- Committee:
  - Professor Henry Lam
  - Professor Marina Epelman
  - Professor Ruiwei Jiang
- Center for Healthcare Engineering and Patient Safety, SCOPES team
- The Seth Bonder Foundation
- The IOE Family at the University of Michigan

Thank You!

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No one can whistle a symphony. It takes a whole orchestra to play it

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CHEPS
http://cheps.engin.umich.edu

CENTER FOR
HEALTHCARE ENGINEERING & PATIENT SAFETY
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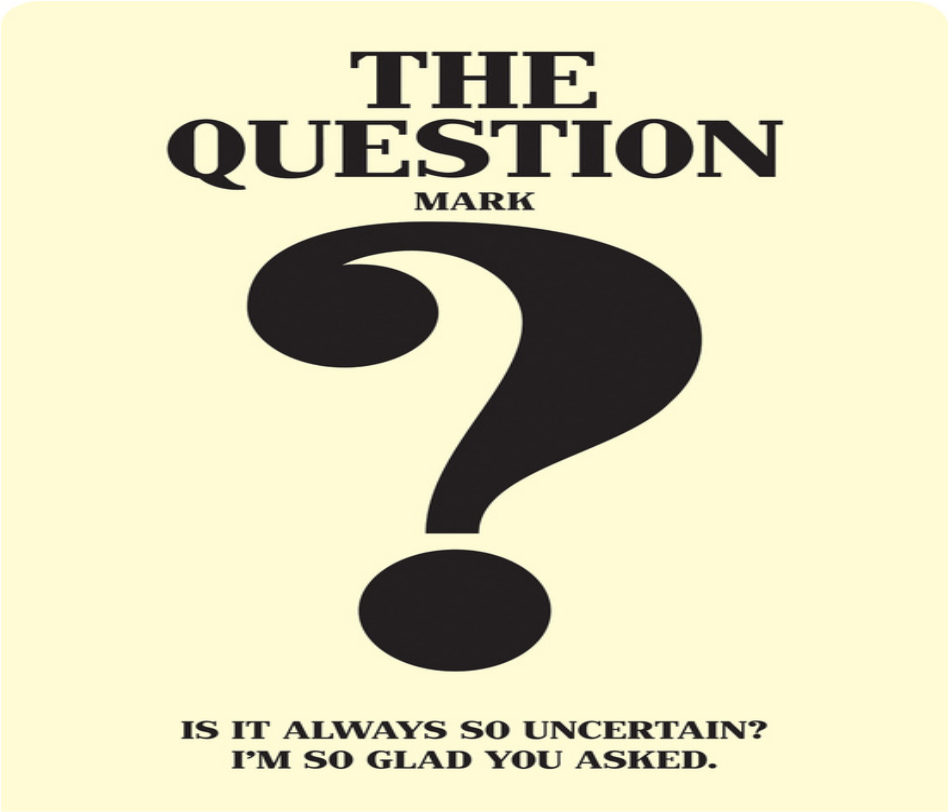
Questions and Discussions



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